ENGINEERING CASE LIBRARY

ECL 138

ELECTRON BEAM COLLIMATOR

Research physicists at Stanford Linear Accelerator Center discovered secondary radiation effects accompanying certain experiments with the electron beam. Because of these effects, the beam's cross section was difficult to define. The scientists asked the Research Area Department at SLAC to design a collimator, an adjustable device to block out the outer portion of the beam allowing only the central beam core to pass through. Dr. Ed Seppi, head of the Research Area Department, gave the job to Mr. Aaron Baumgarten, who told the case writer how he designed the collimator.

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ELECTRON BEAM COLLIMATOR

Introduction

In April, 1962, the Atomic Energy Commission awarded Stanford University a contract to design and construct at an expected cost of $114,000,000 a two mile long linear electron accelerator. The accelerator was completed in November, 1966, more than twenty years after Stanford scientists began research on linear accelerators. It produces an electron beam of 10 to 20 billion electron volts and is available to scientists from all nations for research in the fields of particle and high energy physics. A 300 foot linear accelerator (the Mark III) capable of producing I Bev electrons was built at Stanford in 1951 and was for a number of years the largest linear accelerator in the country. The Stanford machines, which accelerate electrons along a straight line, have some advantages over machines which accelerate in a circular path. This is due to the fact that high energy electrons travelling in a circular path lose large amounts of energy through radiation. Not only does the lost energy never reach the target, but also it creates a radiation hazard to personnel.

The accelerator, which costs $20,000,000 per year to operate, is essentially a copper pipe 4 inches in diameter and two miles long. An electron beam is produced by injecting electron bunches into one end of the pipe 360 times per second. At the other end of the pipe is a "beam switchyard." Here, the electron beam is steered by magnets into one of several experimental areas, where the beam hits its target. This switchyard arrangement permits scientists to set up one experiment while another is being run.[1]

In certain experiments with the electron beam at the Stanford Linear Accelerator Center, undesirable secondary radiation effects were detected by the research physicists. These effects tended to obscure clear definition of the beam's cross section. The scientists felt that these effects could be eliminated if the electron beam were collimated.

An electron beam collimator is a device that provides an aperture of known dimensions through which the beam can pass. Collimation effectively blocks out the outer portion of the beam's cross section, permitting only the central beam core to pass through. The beam then emerges with the cross section defined by the collimator aperture.

In February of 1969, Dr. Ed Seppi, head of the Research Area Department, requested that an adjustable collimator capable of providing a variable aperture be constructed. He specified a rectangular aperture with maximum dimensions: 3 3/4" wide, and 7/8" high. Because tungsten possesses characteristics desirable for blocking out the beam, the rectangular aperture could be formed by four tungsten blocks, approximately 1 1/2" thick, 1 1/2" high, and 4" wide. Since the physicists did not know the exact position and size of the beam's cross section, they felt that the aperture position, as well as the aperture size should be adjustable. Both of these parameters were to be measurable and reproducible to within .015".

[1]Engineering Case Library, ECL 91A, The Support and Alignment of the Stanford Linear Accelerator (A).

The collimator would be placed in a highly radioactive area which was accessible to personnel only when the accelerator was inactive. The next period of inactivity was scheduled for early April. In addition, to ensure that the beam would not lose energy from collisions with air particles in the environment of the tungsten aperture, the collimator had to become part of the vacuum system enclosing the beam and its targets.

On February 26, 1969, Dr. Seppi assigned the task of building the beam collimator to Aaron Baumgarten. An experienced mechanical engineer, Aaron had been with SLAC for the previous five years. His experience during this time included work on the construction on the two-mile long linear accelerator. It was Aaron's responsibility to see that the collimator was designed, built and installed by the first week in April. Only five weeks were available in which to complete the whole job.

After preparing a concept-layout, Aaron requested the help of Bernie Denton, a Senior Designer. Five of Bernie's eleven years' experience as a Senior Designer had been spent at SLAC. Although not an engineer, Bernie was responsible for completing the details in the final assembly drawings. Bernie transformed Aaron's ideas and sketches into shop drawings which went directly to the machinist for construction. Because of the time limitation, many implementation details of construction were left to the discretion of the experienced shop machinists. Aaron made it a point to be fully informed of the progress in all stages of the collimator's development.

Design and Construction

To define a rectangular aperture that would be movable, as well as adjustable in size, Aaron placed each of the four tungsten blocks in separated parallel planes. Two blocks moved vertically and the other two moved horizontally. (See Figure 1)

These blocks would be moved by servo motors driving threaded pushrods. To seal the vacuum environment of the tungsten blocks from the outside, metal bellows were welded to the pushrods. (See Figure 2)

The collimator housing consisted of a box built up from six aluminum plates. Overall dimensions of the box were approximately: 12" deep, 12" wide, and 7" high. Since it would be much easier to work with aluminum plates than with the assembled box, Aaron decided that all machining of the box sides be performed before they were welded together. Machining complexity was reduced in this manner, and valuable time was saved.

The front and back plates of the box were bored to match the inner diameter of the beam tube. These plates were machined to allow joining with flanges on the beam tube. (See Figure 3)

Aaron designed the top plate of the box to have a large circular opening. This hole would allow access to the box interior during collimator assembly. A seventh plate, a circular top cover for the access hole would mount the vertically moving blocks and their actuators. In contrast, the actuators for the horizontally moving blocks would be mounted

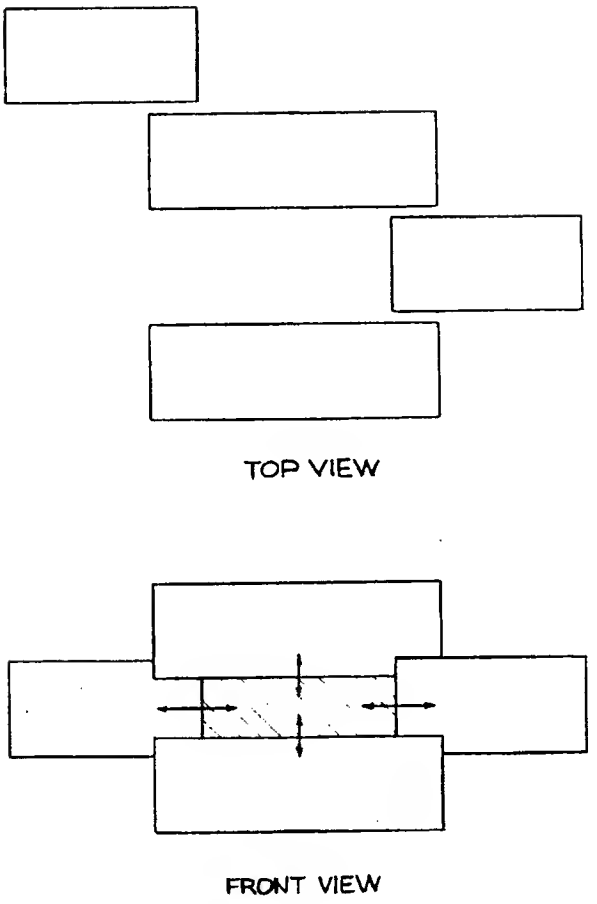


Figure 1. Placement of the Tungsten Blocks

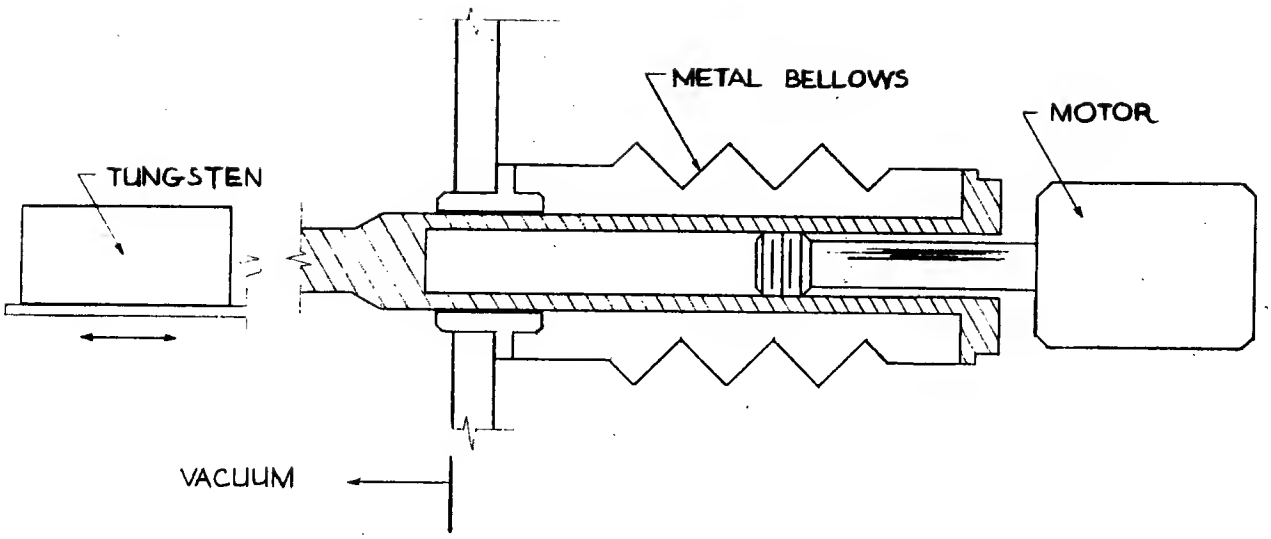


Figure 2. Actuator Assembly for the Tungsten Blocks

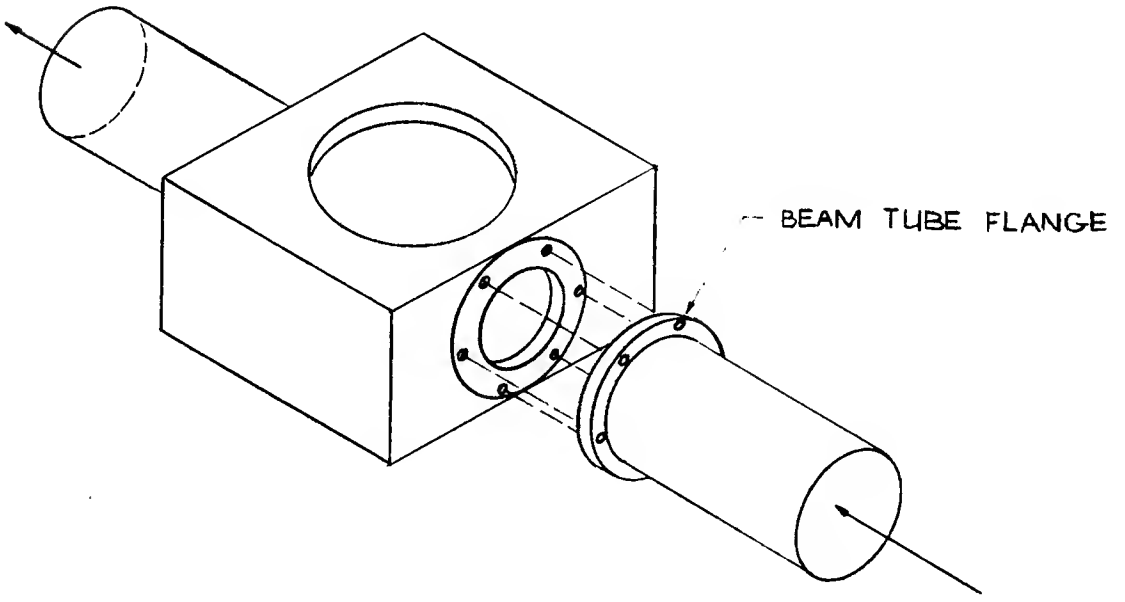


Figure 3. Joining the Collimator to the Beam Tube

on one side of the box, while the blocks would be mounted on the bottom plate of the box. The vertical actuators provided about 1 1/4" of movement, and the horizontal actuators provided about 4" of movement.

Track sliders were designed to mount the horizontally moving blocks, and aluminum frames sliding in anodized aluminum tracks were designed for the vertically moving blocks. (See Figure 4)

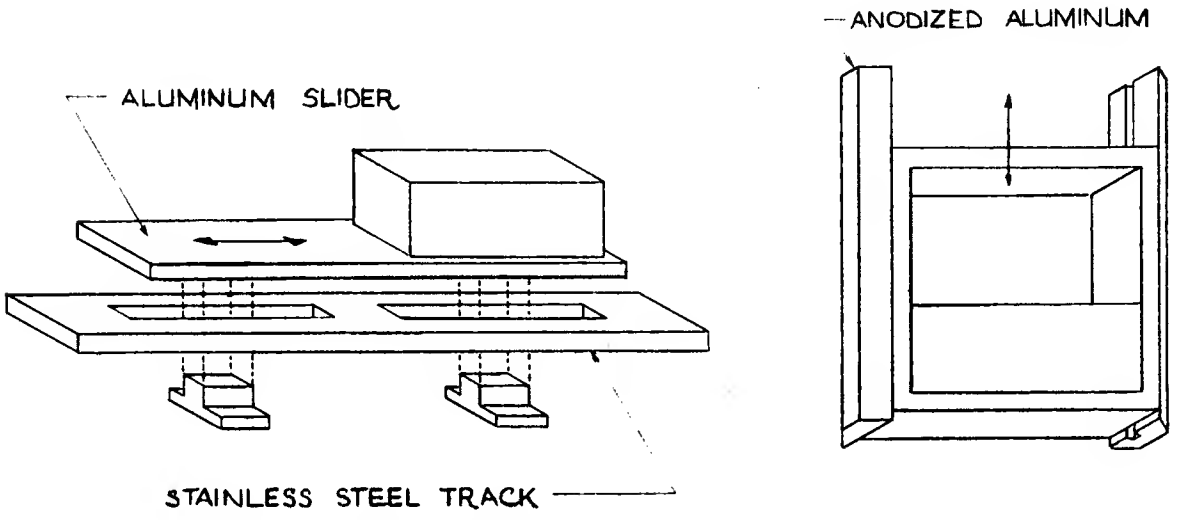


Figure 4. Mountings for the Tungsten Blocks

The two blocks mounted on the horizontal sliders and the other two blocks mounted in the aluminum frames made up the four "jaws" defining the collimator aperture.

It was essential that the aperture defined by the four jaws always be rectangular. Therefore, maintenance of precise jaw positioning was the criterion for collimator assembly.

Assembly

After all the collimator components were built, the following assembly procedure was adopted to ensure precise jaw movement:

1. Aluminum doubler plates were welded to the side of the box that would mount the horizontal actuators, and to the top plate of the box. Mounting bars for the two horizontal tracks were welded to the bottom plate. (See Figure 5)

2. The six sides of the collimator box were then welded together.

3. In one set-up on the mill, the outer surface of the side doubler plate and the uppermost surface of the top doubler plate were finished perpendicular to each other. In

this same set-up on the mill, a fly cutter was used to finish the top surface of the mounting bars parallel to the top surface of the collimator box. (See Figure 5)

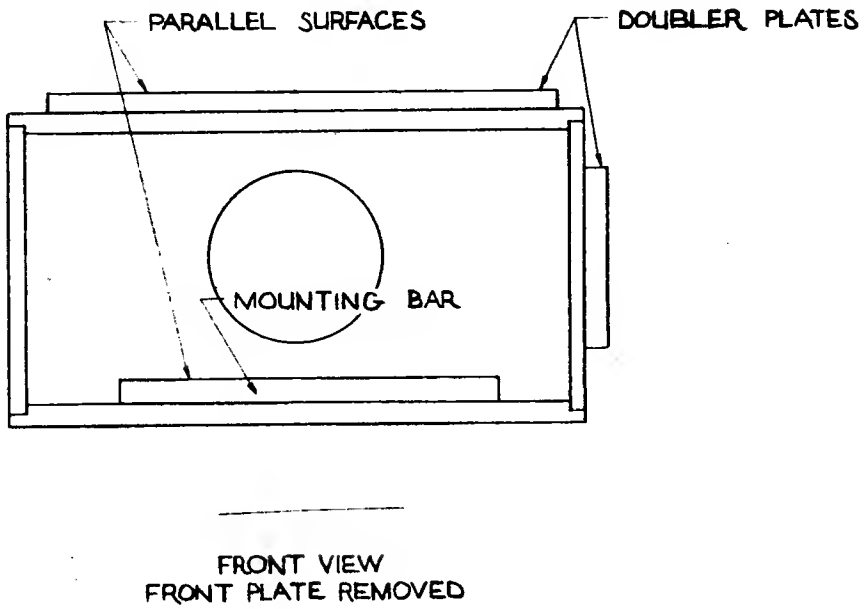


Figure 5. Surfaces Finished Parallel on the Mill

4. To avoid the difficult task of providing collinear movement between the horizontal actuator and the jaw, a slider-pin connection was designed for these components. Whatever error this arrangement introduced in measuring position would be accommodated by calibration. (See Figure 6)

5. Both the top and bottom surfaces of the circular cover plate were carefully machined to be parallel. Since the vertical actuators and jaws were mounted on this one plate, there was no special problem in aligning their movement.

6. This vertical jaw assembly was then bolted to the top of the collimator box.

Jaw Positioning Telemetry

To relay jaw positioning information, Aaron decided to machanically link potentiometer arms with the jaw actuators. Jaw position was then indicated by output voltage on the potentiometers. Linear potentiometers linked directly to the translational motion of the actuators were first proposed as the solution. Unfortunately the appropriate potentiometers would take too long to acquire. However, SLAC did have rotary arm potentiometers readily available, so Aaron coupled these potentiometers to the rotary motion of the servo motors with toothed plastic belts. (See Figure 7)

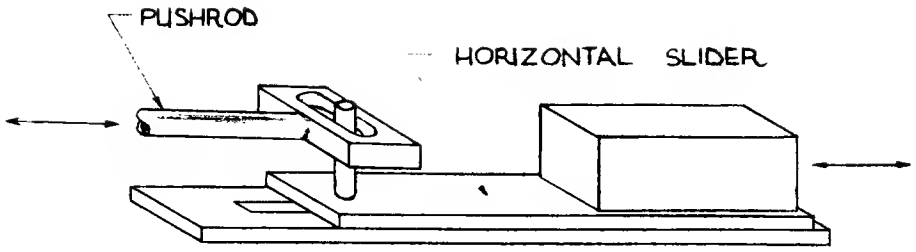


Figure 6. Slider-pin Connection for the Horizontally Moving Jaw and Actuator

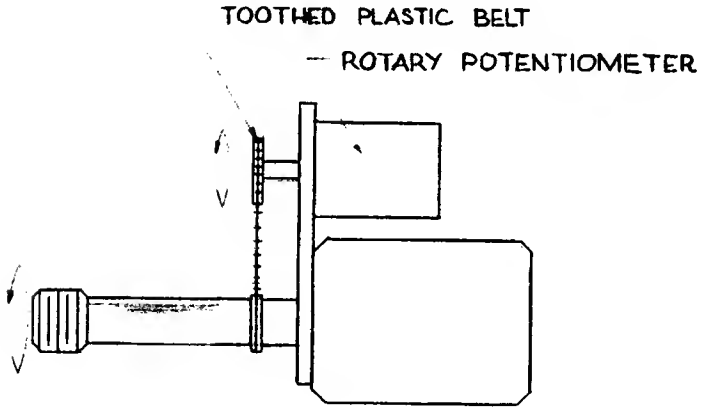


Figure 7. Potentiometer-Servo Motor Linkage

Calibration

It was necessary to reference this telemetry system to fiducials (optical reference points) which would be externally visible. Four optical tooling balls, placed at equal heights above the finished top surface of the collimator box, provided satisfactory reference points for calibration. These externally visible balls defined a horizontal plane with which to reference the position of the vertically moving jaws. A vertical plane, tangent to two of the balls, provided the reference for the horizontally moving jaws. These perpendicular planes could be located with a theodolite.[2] (See Figure 8)

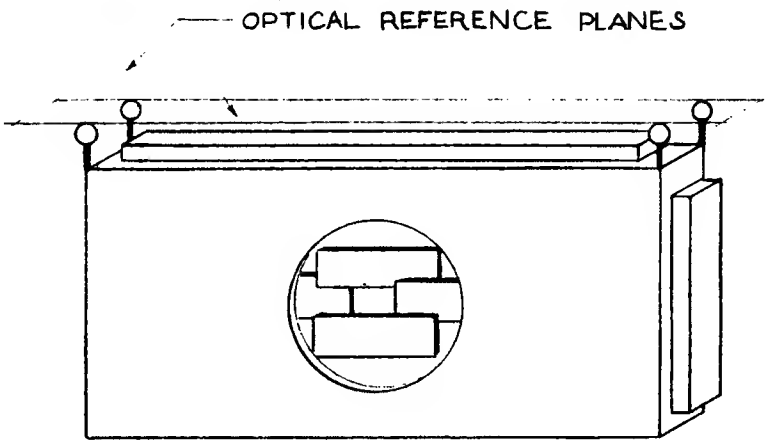


Figure 8. Placement of Optical Tooling Balls

On April 5, 1969, the optical calibration was performed. Repeatability of jaw positioning was within .001". The collimator was installed on April 7, and it received its first beam on April 11. It met or exceeded all of its design specifications. Interestingly, the entire job had cost less than $5,000.

[2]An optical instrument that consists of a sighting telescope, so mounted that it is free to rotate around horizontal and vertical axes, and graduated scales, so that the angles of rotation may be measured. The telescope is usually fitted with a right-angle prism, so that the observer continues to look horizontally into the eyepiece, whatever the variation of the elevation. (Scientific Encyclopedia, D. Van Nostrand Company, Inc., Fourth Edition, 1969, page 1828.)

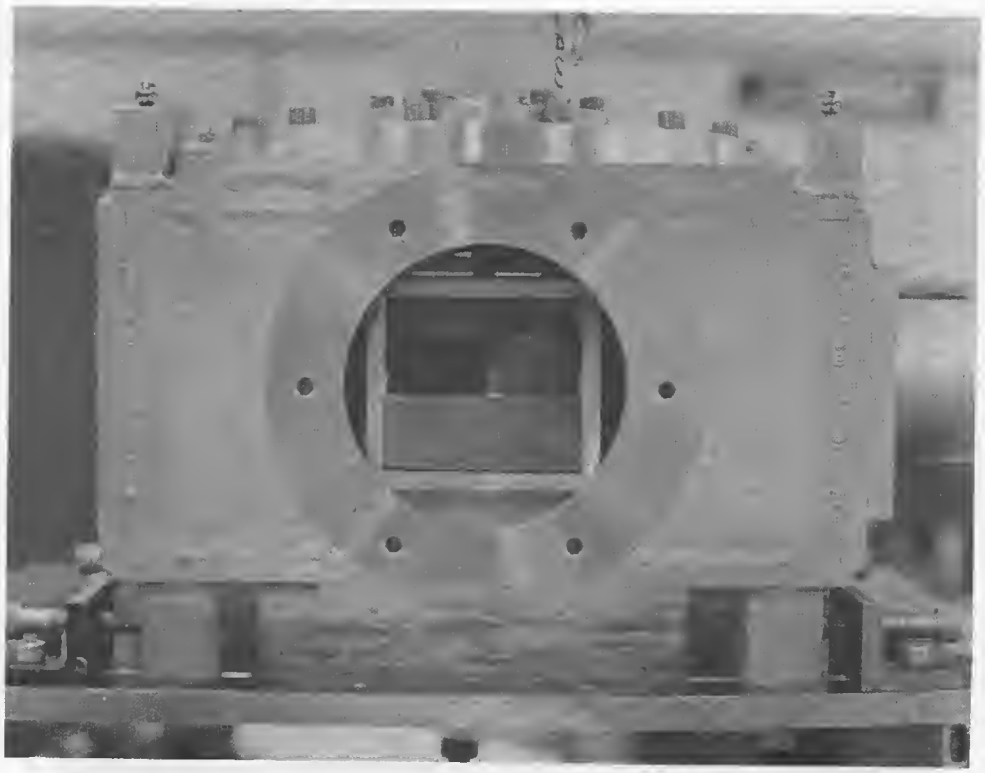


Exhibit 1. Tungsten Jaw Aperture as seen by the Incoming Beam
Note Optical Tooling Balls

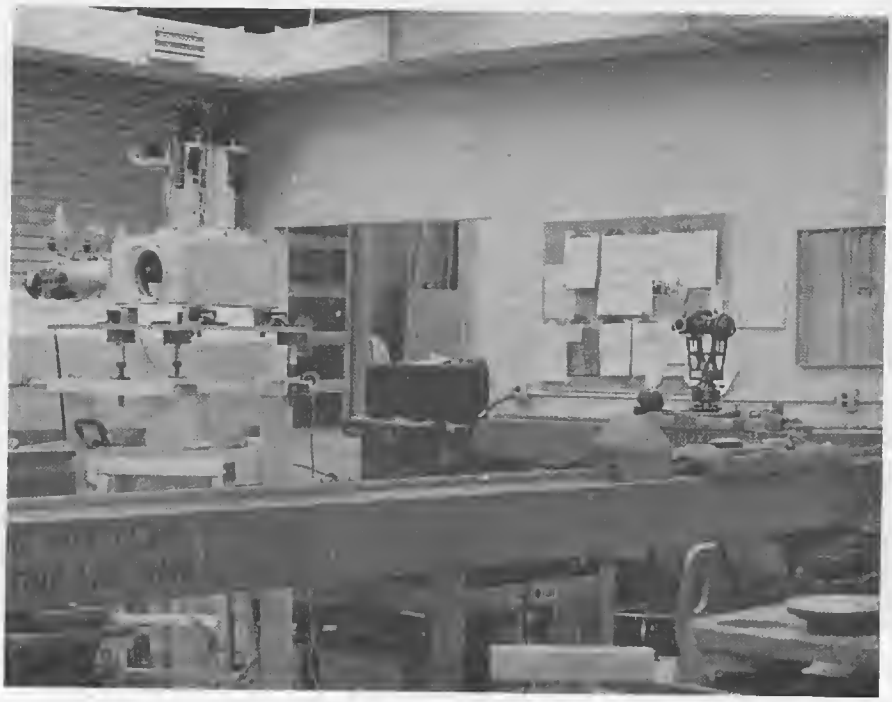


Exhibit 2. Jaw Calibration Set Up Using the Theodolite

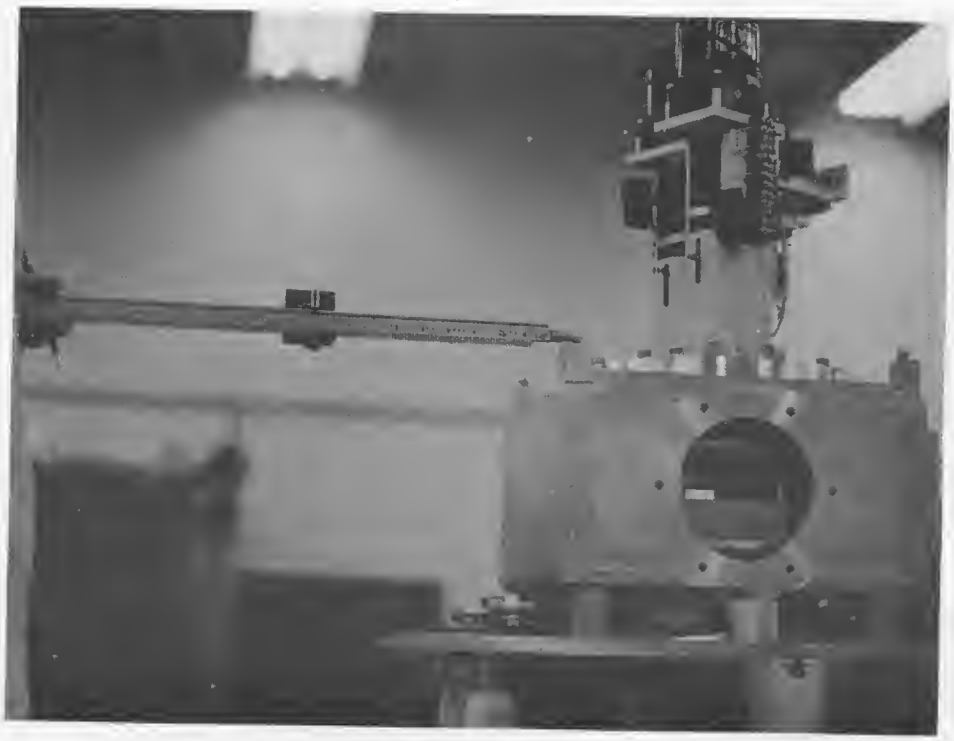


Exhibit 3. Locating Reference Planes
Using Optical Tooling Balls